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FOR

SHIELDING PLATE IN PLASMA FOR UNIFORMITY IMPROVEMENT

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SHIELDING PLATE IN PLASMA FOR UNIFORMITY IMPROVEMENT

FIELD OF THE INVENTION

5   The field of the invention relates generally to a plasma-assisted material process, and more particularly to control of process uniformity across substrate.

BACKGROUND OF THE INVENTION

     Capacitively coupled plasma (CCP) reactors and high density plasma (HDP)

10   reactors, such as inductively coupled plasma (ICP) reactors and electron cyclotron resonant (ECR) plasma reactors, have been widely applied in the semiconductor industry for plasma assisted material process, such as plasma enhanced chemical vapor deposition (PECVD) and plasma etch. A conventional plasma reactor, such as CCP, usually consists of two parallel plate electrodes in a chamber. The reactive

15   nature of the discharged gas in the chamber is sustained due to the radio frequency (RF) voltage on the two electrodes. The typical pressure in the chamber ranges from $10^{-3} - 10$ Torr. High voltage on the electrodes causes ion bombardment on the surface of a substrate.

     HDP reactors, such as those of the ICP type, consist of two set RF coils

20   located outside the plasma chamber. RF power is provided to the chamber by an inductive magnetic field. It is not necessary to have an electrode in the HDP reactor. In general, by applying RF bias voltage to the substrate one can independently control the ion bombardment energy in HDP.

Plasma-assisted material processes are generally carried out in a plasma chamber or reactor. To control the reaction rate across a reticle or wafer, the state of the art approach provides for the end user to adjust operational parameters. For example, the radio frequency (RF) power of the coil or neutral gas pressure may be

5   adjusted. Additionally, the mass flow rate may be adjusted.

However, modification of the above parameters still yields a disproportionate etching or deposition rate on the surface of the substrate, i.e. sometimes significantly higher rates at the center of the substrate than at the edges. Thus, such modifications can yield, at best, only about a 2-3% uniformity across the substrate. Although this

10   represents an improvement over processes performed without such modifications, this level of uniformity still does not meet the specifications for certain applications, such as for etching a quartz/chromium reticle.

With state of the art systems, the end user cannot do anything more to improve uniformity without sacrificing other qualities such as etch selectivity. The

15   end user cannot make structural modifications to the reactor hardware itself, such as, adjustment of coil configuration, chamber size, and pedestal position. Such modifications could produce the desired improvements, but modifications to reactor hardware can only be made by the vendor. Thus, if heightened uniformity is to be achieved by the end-user, it should make use of conventional etching equipment.

20   There is thus a need for a means of attaining better plasma-enhanced material process uniformity using conventional equipment.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements.

5 **Fig. 1** is an illustration of a cross-sectional view of one embodiment of a shielding plate in a plasma reactor, in accordance with the present invention.

Fig. 2 is an illustration of a top-view of two embodiments of shielding plates, in accordance with the present invention.

Fig. 3 is an illustration of a cross-section of plasma densities for various

10 embodiments of plate usage, in accordance with the present invention.

Fig. 4 is an illustration of radial ion flux rates for the various embodiments of plate usage in Figure 3, in accordance with the present invention.

Fig. 5 is an illustration of a cross-section of plasma potentials for the various embodiments of plate usage in Figure 3, in accordance with the present invention.

15 **Fig. 6** is an illustration of a cross-section of one embodiment of a critical dimension control process, in accordance with the present invention.

Fig. 7 is a flow diagram for one embodiment of a method for optimizing plasma-assisted material process uniformity, in accordance with the present invention.

20 **Fig. 8** is a flow diagram for one embodiment of a method for optimizing a critical dimension control process, in accordance with the present invention.

DETAILED DESCRIPTION

A shielding plate is placed in plasma for plasma-assisted material process

5   uniformity improvement. An apparatus comprising a plasma chamber containing a

plasma for a plasma-assisted material process upon a substrate; a shielding plate

within the plasma chamber to actively direct ion flux to desired areas of the

substrate; and a supporting structure to support the shielding plate within the

chamber is disclosed.

10   The apparatus provides an effective way to control ion flux and optimize the

uniformity of plasma-assisted material processes, such as etching or deposition,

across the surface of a substrate. It can also provide a way to localize reactions on

the substrate. It can also minimize the macro-loading effect due to non-uniform

accumulation of etching by-products, which may cause substrates to become

15   unbalanced. It may also be favorable to current critical dimension control processes.

The apparatus can result in cost savings in the material processes.

The apparatus comprises a shielding plate within a plasma reactor to regulate

the material process. The term plasma-assisted material process will be used

interchangeably with the terms plasma-assisted etching process and plasma

20   enhanced chemical vapor deposition (PEVCD). Further, these terms may be

abbreviated to etching and deposition. In other words, the apparatus is not limited to

etching processes. The term plasma reactor will be used to mean an inductively coupled plasma reactor or other plasma reactor. The plate can regulate ion flux across the substrate during an etch process. Ion flux is the quantity of ions diffusing through and perpendicular to a unit cross-sectional area (i.e., the substrate) per unit

5   time. An ion is an atom or molecule with a positive charge because electrons have been removed or a negative charge because electrons have been added. Negative ions do not diffuse to the chamber wall and substrate because of the electrostatic field in plasma. A plasma is a discharged gas in which some individual atoms are ionized though the total number of positive and negative charges is equal,

10   maintaining an overall electrical neutrality.

The etch rate is the rate of controlled surface erosion upon a substrate. In one embodiment, the substrate subject to plasma-assisted etching is a reticle. In another embodiment, the substrate is a silicon wafer. The terms substrate, reticle, and wafer will be used interchangeably. In other embodiments, the substrate is polysilicon,

15   aluminum or copper. Although the detailed mechanism of why ions play such a critical role in the etching process is still unclear, it is believed that etch rate is proportional to both ion flux and active species flux. Therefore, etch uniformity can be optimized by controlling these fluxes. Similarly, ion flux is proportional to the rates of PECVD.

The radius and the location of the plate may depend upon the type of etch process performed. By adjusting the size, location and geometry of the plate within the plasma reactor, the ion flux can be actively controlled.

Fig. 1 is an illustration of a cross-sectional view of one embodiment of a

5   shielding plate in a plasma reactor, in accordance with the present invention. Shielding plate 110 is supported by support 120. Support 120 sets upon pedestal 150 within plasma reactor 140. The term plasma reactor will be used interchangeably with plasma chamber. In one embodiment, the plate 110 is supported by three supports 120. In an alternate embodiment, shielding plate 110 is suspended from

10   above the reticle 130. Alternatively, shielding plate 110 is located to the side of reticle 130. Reticle 130 sets upon pedestal 150. Neutral, reactive gas, such as but not limited to CF_4 or CHF_3 enters chamber 140 through gas inlet 160. When the neutral gas enters the strong electrical field within chamber 140, it becomes a plasma. The plasma fills chamber 140 and ions flow anisotropically through the plasma sheath

15   and hits the wafer vertically. Anisotropic flow varies with direction. The presence of the shielding plate 110 directs ion flux with respect to the substrate surface 130. In one embodiment, plasma-enhanced chemical vapor deposition (PECVD) is performed using the plate. In another embodiment, SiO_2 etching is performed.

Since solid objects are plasma density sinks, to minimize the signature effect

20   of the support 120, the distance D between the support and the reticle may be made much larger than mean free path of the etching particles, primarily electrons and

ions. The mean free path is the distance that an ion, electron or atom travels without collision. In one embodiment, the distance between the support and the reticle is 2-3 times greater than the mean free path. It is also preferable for the diameter of the support to be much smaller than mean free path.

5   **Fig. 2** is an illustration of a top-view of two embodiments of shielding plates, in accordance with the present invention. In one embodiment, shielding plates are circular. The size, shape and geometry of the shielding plate is sufficient to cause ion flux from plasma to reticle to be diverted in some way. By diverting ion flux, etch rates can be controlled. In one embodiment, the shielding disk is placed over

10   the center of the reticle to reduce the higher etch rates that normally occur at the reticle center and provide for more uniform etching. In another embodiment, the disk is placed above one side of the reticle to provide for decreased etch rates in that side area.

Shielding plate 210 is a solid circle which may reduce etch rates in the

15   central area of reticle 130 (**Fig.1**). In another embodiment, shielding plate 220 has a radial cutout to suppress etch rates in the edge area of the reticle 130 (**Fig. 1**). A cutout is perforation in a shielding plate. This can achieve axisymmetric etch rate adjustment. In another embodiment, non-radial perforations may be made in the plate to concentrate the etching within a certain area of the reticle.

20   The diameter and thickness of a plate may depend upon the size of the plasma chamber and the reticle. In one embodiment, the dimensions of the plate are

dependent upon the dimensions of the chamber and reticle. For example, the plate

fractionally smaller than the reticle. In one embodiment, the plate has a thickness of

2-5 mm. It is preferable for the plate to have rounded corners on its edges to reduce

the risk of local electrostatic discharge. In one embodiment, the plate and any

5   supporting members are made of a dielectric material, such as but not limited to

quartz or a ceramic. A dielectric material is an insulator through which electrical

current cannot flow.

Figures 3, 4 and 5 demonstrate how numerical simulation can be used to

optimize disk properties. In one embodiment, disk optimization is carried out by

10   numerical simulation.

Fig. 3 is an illustration of a cross-section of plasma densities for various

embodiments of plate usage, in accordance with the present invention. Plasma

density is synonymous to electron density. Plasma densities are measured in number

of ions / cm^3 at 4 mTorr Ar and 600 W of ICP radio frequency power. In the case A

15   embodiment, there was no disk was in the plasma chamber. In the case B

embodiment, a 2-cm radius disk was placed at a height of 5 cm above the reticle. In

the case C embodiment, a 4-cm radius disk was placed at 5 cm above the reticle. In

the case D embodiment, a 4-cm radius disk was placed at 11 cm above the reticle. In

the case E embodiment, a hollow disk, or disk with a radial cutout, having a 10-cm

20   outer radius and a 5-cm inner radius was placed at a height of 5 cm above the reticle.

The projected density contour lines changed significantly in situations where a disk

was present in the chamber. In embodiments B, C, and D where solid disks were used, plasma density in the central area of the reticle was suppressed. In the case E embodiment, a hollow disk suppressed the density at the outer edges of the reticle, because plasma can penetrate the hole in the disk. In yet another embodiment, the

5   location of the disk is altered depending upon changes in chamber pressure or other variables.

Fig. 4 is an illustration of radial ion flux rates for the various embodiments of plate usage in Figure 3, in accordance with the present invention. Ion flux is equal to plasma density multiplied by ion velocity. Ion fluxes across the reticle are

10   measured in terms of a delta value which is equal to the = (maximum ion flux − minimum ion flux) / (average ion flux). The case A embodiment again represents the conventional approach without a disk in plasma. In the embodiments of cases A-E, the disks are of the same size, geometry and location as the corresponding disks in figure 3. The embodiment of case D, a 4 cm radius disk placed at a height of 11 cm

15   above the reticle, produced the best uniformity of ion flux across the surface of the reticle and therefore the most uniform etch rate. The delta value of case D was only 1.5%, as compared to 5% in the Case A embodiment, where no shielding disk was present.

Fig. 5 is an illustration of a cross-section of plasma potentials for the various

20   embodiments of plate usage in Figure 3, in accordance with the present invention. Plasma potential are measured at 4 mTorr Ar 600 W ICP power. Plasma potential

provides that when ion flux emanates from plasma to the reticle, the ions obtain

energy from the surrounding electrical field. This energy is proportional to the

potential difference between the reticle and the plasma. With increased potential and

RF bias, ion bombardment upon the reticle becomes more energetic. Ion

5   bombardment is therefore proportional to the potential difference between the reticle

and the plasma.

Five embodiments, cases A-E, are represented, each with plate geometry,

size and location corresponding to that in **Fig. 3**. To achieve uniform ion

bombardment it is desirable that potential contour lines be as close to parallel to the

10   plane of the reticle as possible. The case D embodiment therefore provides the most

uniform etching because its potential contour lines are nearly parallel to the reticle.

Etching is primarily controlled by two factors, 1) ion and etchant fluxes, and

2) energy flux. Energy flux equals mass flux multiplied by the energy carried by

each ion. Mass flux is the quantity of mass diffusing through and perpendicular to a

15   unit cross-sectional area per unit time. Energy is proportional to plasma potential. In

order to achieve uniform etching, it is necessary to achieve uniform ion and active

neutral fluxes as well as uniform energy flux.

Fig. 6 is an illustration of a cross-section of one embodiment of a critical

dimension control process, in accordance with the present invention. Vertical

20   etching 620 of the reticle 640 is carried out by ions (i) and metastable neutrons (n*).

Horizontal etching 630, however, can be carried out only by neutrons (n*).

Shielding disks may be used to regulate the n* / i+n* ratio and control the rates of

horizontal and vertical etching. By this means, the desired critical dimensions 610

for an etching process may be generated. Photoresistors or mask 650 on top of

reticle 640 prevent etching in the areas of the reticle that are not to be etched. In one

5   embodiment, CD 610 are tailored to fit the requirements of the particular etching

process involved.

Fig. 7 is a flow diagram for one embodiment of a method for optimizing

plasma-assisted material process uniformity, in accordance with the present

invention. At block 705, the optimization process begins. Optimization is based

10   upon the type of material process to be performed and the special needs of each

process. At block 710, the shielding plate size is optimized by simulation. For

example, if the process requires that the etching rate be minimized in a relatively

small area of the reticle, then a smaller disk may be placed above the area. At block

720, the plate location is optimized by simulation. For example, if the process

15   requires that the etching rate over the upper left hand corner of the reticle be

minimized, then a plate can be placed above the upper left hand corner area. The

height of the plate above the reticle may also be optimized to achieve the desired ion

flux. At block 730, the plate geometry is optimized by simulation. For example, if

the process requires that the etching rate be minimized around the edges of the

20   reticle, then a hollow disk, or disk with a cutout, can be used. In one embodiment,

optimizing plate geometry includes making one or more perforations in the plate for

localized etching. In general, the presence of a plate above an area of substrate

decreases the etch rate in that area. In one embodiment, the optimizations in blocks

710, 720, and 730 are carried out by numerical simulation. At block 740, a

determination is made of whether the plate size, location, and geometry provide for

5   the optimal ion flux distribution across the substrate surface and/or whether the

macro-loading effect has been minimized. The macro-loading effect is caused by the

non-uniform accumulation of etching by-products across the substrate. For example,

in one embodiment, etching by-products are more heavily concentrated at the center

of the substrate. This causes the etching rate to be decreased at the center. A

10   shielding plate may be placed above the substrate center to prevent ion flux to the

center and spread the etching by-products uniformly across the substrate. If the

parameters are not optimal at block 740, the process returns to block 710 for further

optimization. When plate size, location, and geometry have been optimized, the

plate is inserted into the plasma chamber at block 750. The presence of the plate

15   diverts ion flux from areas of the substrate beneath the plate. At block 760, the

desired plasma-enhanced material process is carried out. At block 765, the process

ends.

Fig. 8 is a flow diagram for one embodiment of a method for optimizing a

critical dimension control process, in accordance with the present invention. At

20   block 805, the process begins. At block 810, the plate size, location, and geometry

are optimized as in Fig 7. At block 820, the ratio of (neutrons) / (neutrons + ions)

bombarding the plate is regulated by the presence of the plate. For example, the

plate can reduce the ion flux in a certain area of the substrate and thereby increase

the relative number of neutrons in that area. This, in turn increases the rate of

horizontal etching upon the substrate and widens the critical dimensions of the

5   etched cavity. For example, in a chromium etching process, where etching rates are

higher at the reticle center, producing a deeper cavity than at the reticle sides, a plate

could be placed over the center of the reticle to increase horizontal etching rates. By

this, the different cavities across the substrate would have a more uniform width. At

block 830, the rates of horizontal and vertical etching are controlled. At block 840, a

10   determination is made of whether the cavities produced have the desired critical

dimensions. If not, the process returns to block 810 to optimize plate size, location,

and geometry. If the critical dimension process is optimized at block 840, then the

process proceeds to block 850. In one embodiment, blocks 820 and 830 are carried

out by simulation. At block 850, the etching process is carried out. At block 855, the

15   process ends.

It will be further appreciated that the instructions represented by the blocks

in Figures 7 and 8 are not required to be performed in the order illustrated, and that

all the processing represented by the blocks may not be necessary to practice the

invention.

20   In the foregoing specification, the invention has been described with

reference to specific exemplary embodiments thereof. It will be evident that various

modifications may be made thereto without departing from the broader spirit and scope of the invention as set forth in the following claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

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